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Treatment of Inflammatory Arthritis by Synovial Ablation: A Comparison of the Holmium:YAG Laser, Electrocautery, and Mechanical Ablation in a Rabbit Model

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Background and Objective: **Although the majority of patients with immune-mediated inflammatory arthritis are managed conservatively, some patients may require synovectomy if they have persistent pain secondary to chronic unresponsive swelling of a joint. In this study, three methods of synovial ablation using laser energy, electrocautery, and mechanical debridement were compared in an in vivo chronic synovitis rabbit model.**

Study Design/Materials, and Methods: **In the first phase of this study, the optimal laser energy/pulse frequency combination for synovial ablation in this model was determined. In the study's second phase, 48 mature rabbits were then divided into four equal groups: laser synovectomy, electrocautery synovectomy, mechanical synovectomy, and control. Chronic synovitis was induced in both stifles of all treatment groups and in the right stifle of the control rabbits. Synovectomy was performed on one stifle of each rabbit; the contralateral stifle served as a sham-operated control. Six rabbits per group were euthanized 2 weeks and 3 months after surgery, respectively.**

Results: **There were no differences among groups in synovial fluid parameters, except at 2 weeks, when the electrocautery group had significantly more white blood cells than the laser and mechanical debridement groups. Histologic examination revealed that mechanical debridement resulted in significantly more synovial hemorrhage, capillary dilatation, plasma cell infiltration, lymphocyte infiltration, joint capsular defects, and poorer synovial ablation than ablation achieved with either laser energy or electrocautery.**

Conclusion: **Laser energy and electrocautery achieved similar results when used for ablative purposes, although electrocautery did not achieve the same degree of synovial ablation as laser energy.**

Key words: knee joint, laser therapy, synovectomy, synovial membrane

INTRODUCTION

Patients with immune-mediated inflammatory arthritis are generally managed conservatively with drugs and physical therapy [1,2]. In the majority of these patients, these measures are

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effective, but in some, chronic swelling in one or more joints leads to pain and further articular destruction. In the patient with persistent pain secondary to chronic unresponsive swelling of the joint, synovectomy is often considered [1,3–6]. These studies, which have evaluated the short- and long-term results of surgical synovectomy, have revealed several areas of agreement: (1) joint pain and swelling are decreased after surgery, (2) joint mobility is not improved except in the elbow, (3) postoperative outcome is dependent on the degree of preoperative osseous and cartilaginous destruction, and (4) results deteriorate with time [1].

Historically, surgical synovectomy has been performed via arthrotomy, which has typically resulted in postoperative pain and a relatively long period of recovery, with subsequent muscle atrophy and decreased range of motion [7]. With the advent of arthroscopy, surgical synovectomy can now be performed on multiple joints more readily [7]. Typically, mechanical debridement has been the gold standard for performing synovectomy over the past three decades, with arthroscopic synovectomy recently becoming more popular [8]. However, there are limitations to current mechanical instrumentation. Iatrogenic damage to articular surfaces can occur with large instruments in confined joint spaces [9]. Lack of visualization within the joint and hemarthrosis are a few of the intraoperative concerns during arthroscopic synovectomy [10].

The development and approval of lasers for arthroscopic use in the 1980s has led to the development of powerful, efficient, and accurate cutting instruments that can access relatively small joint spaces [9]. The lasers that were first developed either required cumbersome delivery systems or failed to precisely ablate joint tissues [9]. Recent advances in laser technology have allowed for the development of laser probes, such as the holmium:YAG (Ho:YAG) laser, which can cauterize and destroy synovial tissue without damaging the underlying joint capsule. The Ho:YAG laser is particularly well suited for synovectomy because of the following characteristics: (1) its mid-infrared wavelength makes it fiberoptically transmissible in a fluid medium, (2) it is a pulsed laser allowing generation of pulses at 1–20 Hz while only using 10–35 watts of power, (3) its short, 2.1 micron wavelength causes a zone of tissue necrosis approximately 82 microns deep and a zone of thermal effect that is limited to no more than 550 microns in meniscal cartilage, and (4) a pulsed delivery system that quickly ablates tissues and achieves hemostasis while minimizing thermal damage [11]. By using the laser in a near-contact mode of 1–2 mm, the larger spot size allows for more effective synovial ablation and ensures instantaneous coagulation. Enough thermal effect is created to provide excellent hemostasis without significantly carbonizing the surrounding tissue.

Although mechanical techniques are the most popular method of achieving synovectomy via arthroscopy, interest in the use of laser energy for achieving synovectomy has increased significantly over the past decade [12]. The purpose of the study reported here was to compare laser energy to mechanical means for achieving synovectomy in an immune-mediated inflammatory arthritis rabbit model. In addition, since some investigators have questioned whether more expensive laser technology has significant advantages to the far less expensive electrocautery devices, we also compare these synovectomy methods to electrocautery-induced synovectomy.

MATERIALS AND METHODS

Phase I—Comparison of Laser Energy/Pulse Frequency for Synovectomy

In phase I of this study, six different laser energy/pulse frequency combinations were compared at 72 hours after surgery to determine the ideal laser energy for achieving synovectomy. Forty mature New Zealand White rabbits, ranging in weight from 3.8 to 5.6 kg (4.6 ± 0.4 kg, mean ± SD), were used for this phase of the study. The rabbits were divided using a randomized block design into eight groups of five rabbits. Groups included six laser treatment groups and two control groups. Chronic synovitis was induced in all rabbits by subcutaneous injection of 4 mg ovalbumin (Sigma Chemical, St. Louis, MO) in 1 ml of Freund's incomplete adjuvant (Sigma Chemical) as described by Consden et al. [14] Fourteen days later, the right stifle of each rabbit was injected with 4 mg ovalbumin and 1 ml saline for induction of immune-mediated arthritis. The contralateral stifle was a normal un-injected control joint.

Fourteen days following the induction of arthritis, the animals were induced with ketamine (25 mg/kg, IV) and diazepam (3 mg/kg, IV), and then were maintained on halothane and oxygen. Both stifles were clipped and aseptically prepared for surgery. A 5-cm central incision was made over the stifle joint, and arthrotomies with two

1-cm portals were created in the patellofemoral joint using a scalpel, one medially and one laterally. A 1 cm^2 synovectomy was performed using a 1.7 mm laser handpiece (InfraTome™, Coherent, Palo Alto, CA) and a Ho:YAG laser (VersaPulse®, Coherent, Palo Alto, CA). The laser handpiece was held approximately 1 mm away from the synovial surface and was moved over the tissue using a paintbrush motion. The procedure was performed in an open fashion using saline irrigation. Following the procedure, the joint capsule, subcutaneous tissue, and skin were closed routinely.

Six laser energy/pulse frequency combinations were evaluated in both arthritic and nonarthritic stifles of each animal in the experimental groups: 0.5 joules/5 pulses per sec (0.5 J/5 Hz), 0.5 joules/10 pulses per sec (0.5 J/10 Hz), 1.0 joules/5 pulses per sec (1.0 J/5 Hz), 1.0 joules/10 pulses per sec (1.0 J/10 Hz), 1.5 joules/5 pulses per second (1.5 J/5 Hz), and 1.5 joules/10 pulses per sec (1.5 J/10 Hz). The total energy deliverd to each joint was recorded. The sham-operated control had an arthrotomy performed on both arthritic and nonarthritic stifles without laser ablation of the synovial tissue. The nonoperated control animals had antigen induced arthritis in the right stifle joint but had no surgical intervention.

All eight groups of rabbits were sacrificed at 72 hours after surgery. The stifles were harvested and analyzed grossly for edema, hemorrhage, charring, and joint capsular defects. The tissue surrounding the joint capsule was removed and the stifles were fixed in 4% formaldehyde/1% glutaraldehyde in phosphate buffer at 4°C. Following fixation, the medial and lateral joint capsule and underlying synovial tissue were removed and processed for histological staining with hematoxylin and eosin. Slides were analyzed for depth of penetration and ability of the energy/pulse frequency combination to remove inflamed synovial tissue without injuring the underlying joint capsule and surrounding fibrous tissue. A subjective scoring system was utilized to grade each slide on a scale from 0 to 3 (0 = none, 1 = mild, 2 = moderate, 3 = severe) for the following parameters: hemorrhage, dilated capillaries, coagulation necrosis, plasma cells, lymphocytes, heterophils, synovial proliferation, synovial ablation, and joint capsular defects.

Phase II—Comparison of Laser, Electrocautery, and Mechanical Synovectomy

In Phase II of this study, three different methods of ablating synovial tissue were compared at 2 weeks and 3 months after surgery to determine the ideal method for achieving synovectomy. Forty-eight mature Flemish Giant/Chinchilla cross rabbits or New Zealand White rabbits with a weight range of 3.3–5.4 kg (4.0 ± 0.4 kg) were used for this phase of the study. Rabbits were randomly and equally divided, utilizing a randomized block design, into four subgroups: laser synovectomy, electrocautery synovectomy, mechanical synovectomy, and nonoperated controls. Six rabbits from each group were sacrificed at 2 weeks after surgery, and six rabbits from each group were sacrificed at 3 months after surgery.

In all animals, immune-mediated arthritis was induced in both stifles, as described for phase I of the study, except for the nonoperated control animals, which had arthritis induced in the right stifle joint only. Fourteen days after induction of immune-mediated arthritis, the experimental animals were anesthetized identically to phase I and both stifles were clipped and aseptically prepared for surgery. Surgical exposure of the medial and lateral compartments of the patellofemoral joint was identical to phase I. Based on the results of phase I of this study, the laser synovectomy of the right stifle joint was performed at 0.5 joules/10 pulses per second, utilizing the previously described 1.7 mm laser handpiece and Ho:YAG laser. The laser handpiece was held approximately 1 mm away from the synovial tissue and moved over the tissue in a paintbrush motion. The electrocautery group received synovectomy of the right stifle using a Bard Electrocautery system (Model 5000, Bard Electro Medical Group, Englewood, CA) with a coagulation output of 420 kHz and an output power of 20 watts. The electrocautery handpiece was held approximately 1 mm away from the synovial tissue and was moved in a similar manner as the laser handpiece. The mechanical synovectomy group received mechanical synovectomy of the right stifle joint using a 3.2-mm flat end cutter (Hall Surgical, Santa Barbara, CA) at 120 rotations/min. The flat-end cutter was in contact with the synovial tissue. The left stifle joints of the three experimental groups received respective sham operations at the time of surgery. Rabbits in each group were administered one perioperative dose of antibiotics (enrofloxacin, 2.2 mg/kg, IM). The control group did not receive any surgical intervention.

Synovial fluid samples were collected aseptically from the right and left stifle joints of rabbits after surgery. Arthrocentesis was performed

at intervals of 48 hr, 96 hr, 7 days, and 2 weeks for the 2 week group, and at intervals of 48 hr, 96 hr, 7 days, 2 weeks, 1 month, 2 months, and 3 months for the 3 month group. Samples were placed on slides and stained with Wright Giemsa and analyzed for WBC numbers, RBC numbers, mucin quality, percent heterophils, and percent mononuclear cells. Because of the difficulty in obtaining sufficient joint fluid from stifle joints, WBC and RBC numbers and cell types were estimated by counting five high-powered fields (20× for WBCs, 40× for RBCs) per joint fluid smear. Total protein was measured using a refractometer (AO Scientific Instruments, Keene, NH).

After euthanasia, the stifles were analyzed grossly and microscopically, as described for phase I of this study. The tissues surrounding the joint capsule were removed and prepared for analysis in a manner similar to that used for samples in Phase I.

For phase I of the study, the Kruskal-Wallis test was used to compare among groups for the subjective histologic parameters evaluated. For phase II, the mean ± SD was calculated for joint fluid total protein and the cellular parameters were evaluated. Three-way analysis of variance (ANOVA) was used to evaluate the effect of time, treatment (laser, electrocautery, mechanical), and sham vs. treatment on the synovial fluid parameters evaluated. For the subjective histologic parameters, the Kruskal-Wallis test was used to compare among groups. When the Kruskal-Wallis test revealed differences between groups for the histologic scores, multiple comparisons between groups (i.e., laser vs. mechanical, laser vs. electrocautery, mechanical vs. electrocautery) were performed with the Wilcoxon rank sum test to further evaluate the differences between groups. All differences were considered to be significant at a probability level of 95% ($P < 0.05$). All statistical analyses were performed with a commercially available software program (SAS Institute, Cary, NC).

RESULTS

Phase I—Identification of Optimal Laser Energy/Pulse Frequency

The gross examination of the joints at 72 hr revealed incrementally increased ablation and damage to the synovium and underlying fibrous joint capsule at higher laser energy densities.

Control. Both right and left stifles grossly appeared normal. On dissection the arthritic right stifle had a slightly thickened and roughened joint capusle. No swelling or edema of the subcutaneous tissue was present.

Sham control. The soft tissue of the right and left stifles had mild edema and swelling. No tissue charring was present, and tissue necrosis was minimal.

0.5 J/5 Hz. The subcutaneous tissue had little thermal charring as compared with the later groups. Mild edema and swelling of soft tissue was present in both stifles, and there was slight thickening of the joint capsule in the right stifle.

0.5 J/10 Hz. The stifles had a slight brownish-red color to the subcutaneous tissue. Mild edema and swelling of the soft tissues was present.

1.0 J/5 Hz. The soft tissue of the right and left stifles was extremely edematous and swollen. The subcutaneous tissue was blackened (appeared charred) and flaky. Full-thickness defects of the joint capsular were present so that bone was exposed after the skin was excised. The remaining joint capsular tissue was necrotic and difficult to cut for histological analysis.

1.0 J/10 Hz; 1.5 J/5 Hz; 1.5 J/10 Hz. The stifles in these groups had the same gross appearance as those in 1.0 J/5 Hz group. In addition, hematomas covered many stifles and full-thickness defects of the joint capsule were more pronounced in these groups.

Histologic Examination (Table 1)

Control group. Histologic analysis of tissue samples from the immune-mediated arthritic stifle showed evidence of immune-mediated arthritis (synovitis) due to the infiltration of plasma cells and heterophils. Heterophils are the rabbit equivalent of neutrophils in humans and are associated with acute inflammatory responses. Cells of the intact synovial membrane were hypertrophied and proliferative, with small blood vessels that were dilated and congested with blood (Fig. 1a). The synovial membrane of the normal left stifle showed no evidence of immune-mediated arthritis. The synovium had no cellular hypertrophy nor proliferation.

Sham control. Histologic analysis of tissue samples from the immune-mediated stifles demonstrated plasma cell and heterophil infiltration consistent with immune-mediated arthritis. The synovium was intact and the cells were enlarged and proliferating. Tissue samples from the normal stifle had mild infiltration of heterophils, and

TABLE 1. Histologic Comparison of Six Laser Energies Used for Synovial Ablation of Joints with Immune-Mediated Arthritis 72 Hours After Surgery

Synovial parameter evaluated	Histologic grade[a] (median, range)							
	Joules/pulse per second						Normal control[b]	Sham control[c]
	0.5/5	0.5/10	1.0/5	1.0/10	1.5/5	1.5/10		
Hemorrhage[d]	3 (3,3)	3 (3,3)	3 (3,3)	3 (3,3)	3 (3,3)	3 (3,3)	0 (0,0)	1 (1,1)
Dilated capillaries[d]	3 (3,3)	3 (3,3)	2 (2,3)	3 (3,3)	3 (3,3)	3 (3,3)	3 (3,3)	3 (3,3)
Coagulation necrosis[e]	0 (0,1)	1 (0,1)	3 (2,3)	3 (2,3)	3 (3,3)	3 (3,3)	0 (0,0)	0 (0,0)
Plasma cells[e]	1 (1,1)	1 (1,1)	1 (1,2)	1 (0,1)	1 (0,1)	0 (0,1)	3 (3,3)	3 (3,3)
Lymphocytes[e]	1 (1,1)	1 (1,1)	1 (1,2)	1 (0,1)	1 (0,1)	0 (0,1)	3 (3,3)	3 (3,3)
Heterophils[d]	1 (1,1)	1 (1,1)	1 (1,1)	1 (1,1)	1 (0,1)	1 (1,1)	0 (0,0)	1 (1,2)
Synovial proliferation[e]	2 (2,2)	1 (1,2)	1 (1,1)	1 (1,1)	1 (1,1)	1 (1,1)	3 (3,3)	3 (3,3)
Ablation[e]	0 (0,1)	2 (2,2)	3 (3,3)	3 (3,3)	3 (3,3)	3 (3,3)	0 (0,0)	0 (0,0)
Joint capsular defects[e]	0 (0,0)	0 (0,0)	3 (2,3)	3 (3,3)	3 (3,3)	3 (3,3)	0 (0,0)	0 (0,0)

[a]Grading scale: 0 = none, 1 = mild, 2 = moderate, 3 = severe.
[b]Nonoperated control stifle with immune-mediated arthritis. This group was significantly different from the experimental groups for each parameter, except for dilated capillaries.
[c]Sham-operated control stifle with immune-mediated arthritis. This group was significantly different from the experimental groups for each parameter, except for dilated capillaries and heterophils.
[d]No significant differences among experimental groups for this parameter ($P > 0.05$).
[e]Significant differences among experimental groups for this parameter ($P < 0.05$).

the synovium was intact and normal in appearance.

0.5 J/5 Hz. Histologic analysis of tissue samples from the immune-mediated arthritic stifle showed evidence of immune-mediated arthritis due to the infiltration of plasma cells and heterophils. The synovial membrane had been removed in these samples and had been replaced by a mass of inflammatory cells. The underlying joint capsule and connective tissue were not damaged at this laser setting (Fig. 1b). The synovial membrane of the sham-operated stifles showed no evidence of immune-mediated arthritis (plasma cells not present), although inflammatory cells (heterophils) were present.

0.5 J/10 Hz. The synovial membrane of the experimental stifle was removed at this laser setting, with no damage to the underlying joint capsule. Evidence of immune-mediated arthritis was present due to the presence of plasma cells and heterophils, although the synovial lining had been removed. Red blood cells and dilated blood vessels were also apparent in the section. The underlying joint capsule and connective tissue were not damaged by this laser setting. Tissue samples from the sham-operated stifles showed no evidence of immune-mediated arthritis; however, heterophils were present. Edema and hemorrhage were slight, and the synovium was removed by this laser setting, with no damage to the underlying tissue.

1.0 J/5 Hz; 1.0 J/10 Hz; 1.5 J/5 Hz; 1.5 J/10 Hz. Histologic analysis of tissue samples from the experimental stifles of these groups showed evidence of immune-mediated arthritis due to the presence of plasma cells and heterophils. Numerous dilated blood vessels were apparent in the remaining tissue and were congested with blood and inflammatory cells. These laser settings removed the synovial tissue, but also severely damaged the underlying joint capsule and soft tissue (Fig. 1c). Tissue samples from the sham-operated stifles were infiltrated with heterophils; however, plasma cells were not apparent, which is identical to the other experimental groups.

Phase II—Comparison of Laser, Electrocautery, and Mechanical Ablation

Based on the results of the phase I study, the laser energy/pulse frequency combination for the laser synovectomy group was set at 0.5 J/10 Hz. The time required to achieve synovectomy in the laser group was 6.0 ± 1.3 min. The total energy utilized to ablate the patellofemoral synovial joint capsule in the stifle joint was 0.38 ± 0.18 kJ. Although an accurate determination of the joint capsular surface area ablated could not be determined, we estimated that approximately 4 cm^2 was ablated, yielding an energy density delivered to the tissue of 95 J/cm^2.

Joint Fluid Analysis

There were no significant differences among the three groups for protein concentration, WBCs,

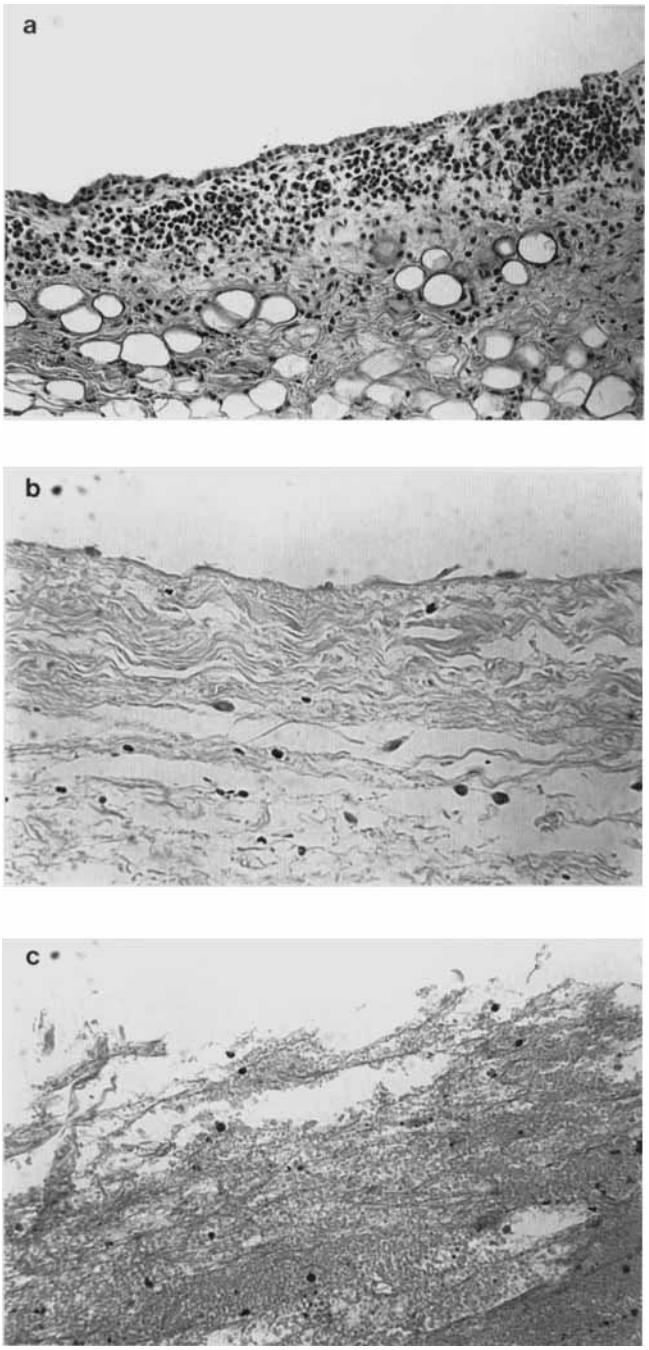

Fig. 1. Histology of the synovial membrane in an immune-mediated arthritis rabbit model 72 hr after surgery. (A) Untreated control demonstrating small cell infiltrate in the synovial membrane with proliferative small blood vessels that were dilated and congested with blood. (B) The 0.5 joules at 10 Hz group, demonstrating removal of the synovial membrane without ablation of the underlying joint capsule and connective tissue. (C) The 1.5 joules at 10 Hz group, demonstrating severe damage and partial ablation of the underlying joint capsule (hematoxylin & eosin, ×100).

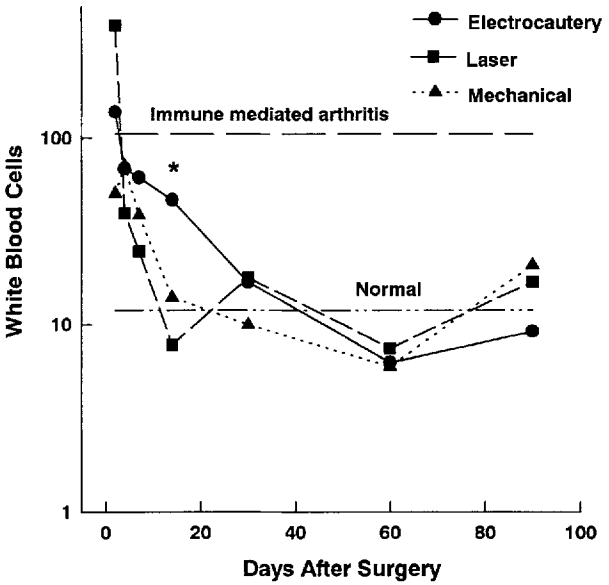

Fig. 2. Line graph illustrating the synovial fluid WBCs in rabbits with immune-mediated arthritis, comparing synovectomies performed with laser energy, electrocautery, and mechanical debridement. *Electrocautery produced a significantly greater WBC count at 2 weeks than in the laser or mechanical debridement groups.

RBCs, mucin clot, percent heterophils, or percent mononuclear cells in either the experimental or sham-operated stifle ($P > 0.05$), except at 2 weeks, when the electrocautery group had significantly higher WBCs than the other two groups (Fig. 2). There were no significant differences between the experimental stifles and the sham-operated stifles for any of the synovial fluid parameters in any group ($P > 0.05$). There was a significant effect caused by time for each of the three groups in protein concentration, WBC count, percent heterophils, and percent mononuclear cells in the experimental stifles only ($P < 0.05$). Protein WBCs, and percent heterophils were high early in the time course and declined, whereas percent mononuclear cells increased over the course of the study.

Gross Findings

At 2 weeks and 3 months, there were no apparent gross differences among the three groups. At 2 weeks, all rabbits had mild swelling, with normal healing of the skin incision. At 2 weeks, the joint capsule was intact in all groups, with only a small amount of joint fluid present. The experimental stifles had slightly more hemorrhage at 2 weeks than the sham-operated stifles, characterized by a red-brown joint fluid in the

TABLE 2. Histologic Analysis of Synovial Ablation Comparing the Holmium:YAG Laser, Electrocautery, and Mechanical Ablation at 2 Weeks After Surgery

Synovial parameter evaluated	Histologic grade[a] (median, range)							
	Laser[b]		Electrocautery		Mechanical ablation		Normal control[d]	Immune-mediated arthritis control[d]
	Operated[c]	Sham	Operated	Sham	Operated	Sham		
Hemorrhage	1 (0,1)*	0 (0,1)	0 (0,1)*	0 (0,0)	2 (1,2)**	0 (0,1)	0 (0,0)	0 (0,0)
Dilated capillaries	2 (2,2)*	3 (2,3)	3 (2,3)**	2 (2,2)	2 (2,3)*,**	2 (1,2)	0 (0,0)	3 (2,3)
Coagulation necrosis	0 (0,0)[NS]	0 (0,0)	0 (0,0)[NS]	0 (0,0)	0 (0,0)[NS]	0 (0,0)	0 (0,0)	0 (0,0)
Plasma cells	1 (0,1)*	3 (3,3)	2 (2,2)**	3 (2,3)	2 (1,2)**	3 (3,3)	0 (0,0)	3 (3,3)
Lymphocytes	1 (0,1)*	3 (3,3)	2 (2,2)*	3 (2,3)	2 (1,2)**	3 (3,3)	0 (0,0)	3 (3,3)
Heterophils	1 (1,1)[NS]	1 (1,1)	1 (1,1)[NS]	1 (1,1)	1 (1,1)[NS]	1 (1,1)	0 (0,0)	0 (0,0)
Synovial proliferation	1 (0,1)*	3 (3,3)	1 (1,1)*,**	3 (3,3)	1 (1,2)**	3 (3,3)	0 (0,0)	3 (3,3)
Ablation	2 (2,3)[NS]	0 (0,0)	3 (1,3)[NS]	0 (0,0)	2 (2,2)[NS]	0 (0,0)	0 (0,0)	0 (0,0)
Joint capsular defects	0 (0,0)*	0 (0,0)	0 (2,0)*	0 (0,0)	1 (1,1)**	0 (0,0)	0 (0,0)	0 (0,0)

[a]Grading scale: 0 = none, 1 = mild, 2 = moderate, 3 = severe.
[b]Laser delivered at 0.5 joules/10 pulses per second. Operated = operated stifle with immune-mediated arthritis; sham = sham-operated stifle with immune-mediated arthritis.
[c]Within a row, operated stifles with the superscripts * and ** are significantly different from each other ($P < 0.05$). NS = operated stifles within a row are not significantly different from each other ($P > 0.05$).
[d]Control = nonoperated rabbits.

TABLE 3. Histologic Analysis of Synovial Ablation Comparing the Holmium:YAG Laser, Electrocautery, and Mechanical Ablation at 3 Months After Surgery

Synovial parameter evaluated	Histologic grade[a] (median, range)							
	Laser[b]		Electrocautery		Mechanical ablation		Normal control[d]	Immune-mediated arthritis control[d]
	Operated[c]	Sham	Operated	Sham	Operated	Sham		
Hemorrhage	0 (0,0)*	0 (0,0)	0 (0,0)*	0 (0,0)	1 (1,2)**	0 (0,0)	0 (0,0)	0 (0,0)
Dilated capillaries	1 (1,1)[NS]	1 (0,1)	1 (1,1)[NS]	1 (1,1)	1 (1,2)[NS]	1 (1,2)	0 (0,0)	2 (2,3)
Coagulation necrosis	0 (0,0)[NS]	0 (0,0)	0 (0,0)[NS]	0 (0,0)	0 (0,0)[NS]	0 (0,0)	0 (0,0)	0 (0,0)
Plasma cells	0 (0,1)*	1 (1,2)	1 (0,1)*	1 (0,1)	1 (1,2)**	1 (1,2)	0 (0,0)	3 (3,3)
Lymphocytes	0 (0,1)*	1 (2,2)	1 (0,1)*	1 (0,1)	1 (1,3)**	1 (1,3)	0 (0,0)	3 (3,3)
Heterophils	0 (0,0)[NS]	0 (0,0)	0 (0,0)[NS]	0 (0,0)	0 (0,0)[NS]	0 (0,0)	0 (0,0)	0 (0,0)
Synovial proliferation	1 (0,1)[NS]	2 (0,2)	1 (0,2)[NS]	1 (1,2)	1 (0,2)[NS]	1 (0,2)	0 (0,0)	3 (3,3)
Ablation	2 (2,2)*	0 (0,0)	1 (1,2)**	0 (0,0)	1 (1,2)**	0 (0,0)	0 (0,0)	0 (0,0)
Joint capsular defects	0 (0,0)*	0 (0,0)	0 (0,0)*	0 (0,0)	1 (0,1)**	0 (0,0)	0 (0,0)	0 (0,0)

[a]Grading scale: 0 = none, 1 = mild, 2 = moderate, 3 = severe.
[b]Laser delivered at 0.5 joules/10 pulses per second. Operated = operated stifle with immune-mediated arthritis; Sham = sham-operated stifle with immune-mediated arthritis.
[c]Within a row, operated stifles with the superscripts * and ** are significantly different from each other ($P < 0.05$). NS = operated stifles within a row are not significantly different from each other ($P > 0.05$).
[d]Control = nonoperated rabbits.

joint cavity. By 3 months, there were no gross differences between sham-operated and experimental joints. The experimental joints appeared grossly normal and could not be distinguished from the normal control joints.

Histological Examination (Tables 2 and 3)

The mechanical abrasion group had significantly poorer histologic scores than the laser and electrocautery groups for the majority of histologic parameters evaluated ($P < 0.05$). At 2 weeks, mechanical abrasion resulted in more synovial hemorrhage, more plasma cell infiltration, more lymphocytes, more synovial proliferation, and more joint capsular defects than the laser and electrocautery groups (Table 2). At 2 weeks, the laser group scored better than the electrocautery group only in plasma cell infiltration and dilated capillaries in the synovium. By 90 days, the mechanical abrasion group continued to score more poorly than the other two groups in hemorrhage, plasma cell infiltration, lymphocyte numbers, synovial ablation, and joint capsular defects ($P < 0.05$) (Table 3; Fig. 3). The laser group scored better than the electrocautery group in the degree of synovial ablation only ($P < 0.05$).

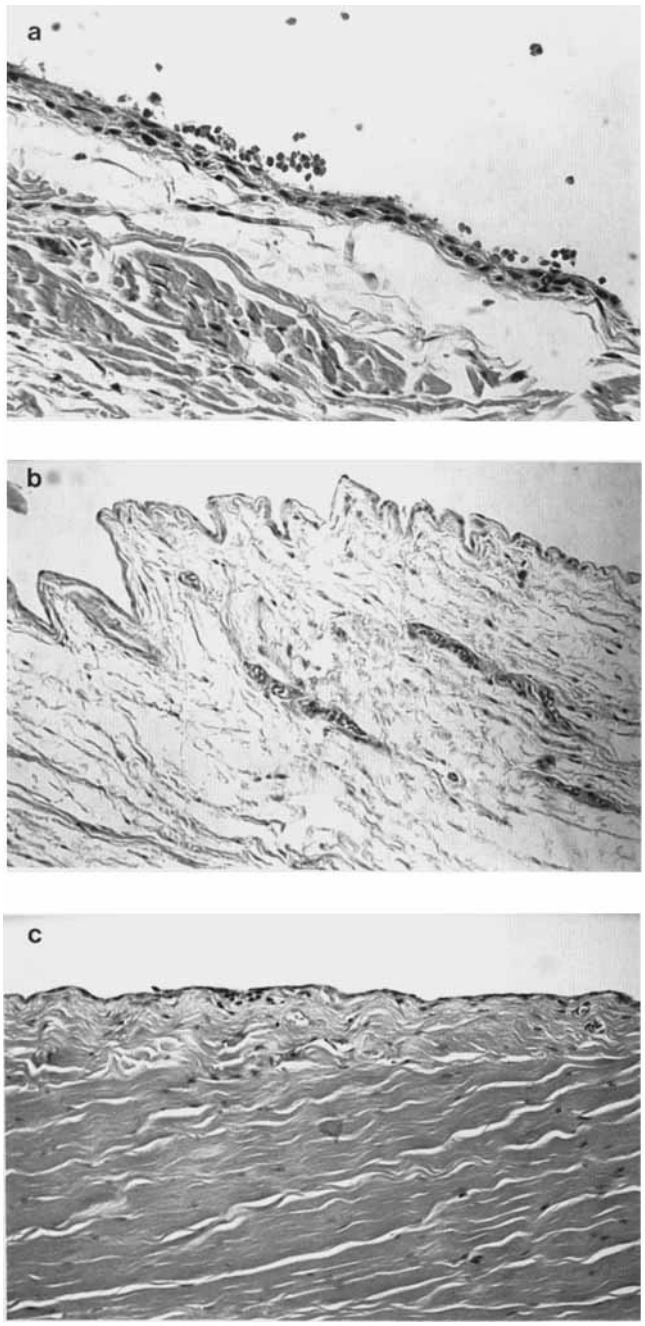

Fig. 3. Histology of the synovial membrane in an immune-mediated arthritis rabbit model. (**A**) Mechanical debridement group at 3 months, demonstrating more synovial hemorrhage and mononuclear infiltration than the electrocautery (**B**) or laser treatment (**C**) groups. (hematoxylin & eosin, ×45).

DISCUSSION

This study demonstrates that the classic method of synovial ablation for immune-mediated arthritis, mechanical debridement [1,3–7], results in significantly more synovial hemorrhage, capillary dilatation, plasma cell infiltration, lymphocyte infiltration, and joint capsular defects, and in poorer synovial ablation, than ablation achieved with either laser energy or electrocautery. Laser energy and electrocautery achieved similar results when used for ablative purposes, although electrocautery resulted in more synovial fluid WBCs at 2 weeks after surgery and did not achieve the same degree of synovial ablation as laser energy. Importantly, both of these techniques significantly reduced the small cell infiltrate into the synovial tissue compared with sham-operated controls by 2 weeks. Future studies should be performed comparing these two modalities to determine if these minor differences are significant in human patients. If human studies reveal few significant differences between these treatment modalities, then the far cheaper electrocautery devices may be the method of choice for achieving synovial ablation in patients with immune-mediated arthritis.

As outlined earlier, surgical treatment of patients with immune-mediated arthritis is a rarity today with the advent of more sophisticated immune-modulating and anti-inflammatory drugs [2]. Despite these advances, there remains a minority of patients who continue to have chronic swelling in one or more joints despite effective control in the remaining joints. If an ablative technique is identified that is both effective and long lasting, then these patients could be treated with synovial ablation without having to further increase and/or alter the immune-modulating or anti-inflammatory drugs they receive.

Historically, mechanical debridement has been used with mixed results [1,3–7]. Mechanical synovectomy results in reduction of joint pain and swelling, but rarely results in increased mobility (except in the elbow), and the outcome deteriorates with time. Perhaps, synovial ablation with laser energy or electrocautery would be more effective and long lasting because a more thorough ablation can be achieved with less synovial hemorrhage and diminished mononuclear cell infiltration. Moreover, applying laser energy or electrocautery in the presence of a fluid medium may further minimize tissue damage by absorbing and dissipating heat away from the tissue, thereby reducing thermal damage. The results in this rabbit study must be corroborated in a human study before either of these techniques can be recommended.

The results of this study confirm a previous report comparing the Ho:YAG laser to mechani-

cal debridement for treatment of chronic synovitis in a rabbit model [14]. Similar to the study reported here, the investigators reported that laser synovectomy resulted in a smooth synovial surface at 3 months after surgery. In contrast, the investigators reported that mechanical ablation resulted in a coarse and villous surface at 3 months after surgery [14]. In the study reported here, mechanical synovectomy resulted in a smooth synovial surface at 3 months after surgery, although more mononuclear cell infiltration was present in the mechanical synovectomy group when compared with the other groups. It is unclear why these two studies differ in the gross pathologic results of the 3 month mechanical synovectomy group. Perhaps these differences were secondary to the method utilized to achieve mechanical synovectomy. Although Möller et al. [13] did not report how mechanical debridement was achieved, in the study reported here a flat-end cutter designed for arthroscopy was utilized for the mechanical synovectomy group.

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